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POPULATION DEMOGRAPHICS AND THE CONSERVATION STATUS OF THE UNCOMPAHGRE FRITILLARY *BOLORIA ACROCNEMA* (NYMPHALIDAE)

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ABSTRACT. *Boloria acrocnema* is an endangered relict arctic butterfly restricted to fewer than ten colony sites in southwestern Colorado, USA. Pollard transects were conducted from 1990–94 to establish relative population estimates for the butterfly. Results indicate a period of stability and increase for all three colony sites surveyed, and are a contrast to population estimates recorded in the 1980's. Collecting pressure, livestock grazing and local climate change are discussed as potential factors behind the butterfly's original decline and its more recent stabilization and increase.

Additional key words: alpine habitat, climate change, collecting activity, Pollard transect, Salicaceae.

Boloria acrocnema Gall & Sperling (Nymphalidae) was discovered on Mt. Uncompahgre in the San Juan Mountains, Hinsdale County, Colorado, and subsequently described by Gall and Sperling (1980) as a new species. The taxonomic relationship of *Boloria acrocnema* to *Boloria improba* (Butler) has been reviewed (Gall & Sperling 1980, Britten & Brussard 1992) and some authorities recognize *B. acrocnema* as a valid species (Ferris 1981, Pyle 1981), whereas others consider it a subspecies of the more northern *B. improba* (Scott 1986).

Since 1978, when *B. acrocnema* was discovered, its demography (Brussard & Britten 1989, Seidl 1995, Ellingson et al. 1996, Wasinger et al. 1997), genetic variation (Britten 1991, Britten & Brussard 1992), and adult and larval life history have been studied (Gall & Sperling 1980, Scott 1982, Gall 1984a, Britten & Riley 1994, Seidl 1995, 1996). Researchers found the species to be in decline in the early 1980's and it was listed as Federally endangered in June 1991 (Opler 1990). Hypotheses for the butterfly's decline include: extensive adult collecting pressure, disruption of larval microhabitat by livestock grazing, and prolonged local drought conditions (Gall 1984a, 1984b, Brussard & Britten 1989, Britten 1991, Britten et al. 1994, Seidl & Opler 1994). The intent of this paper is to summarize and extend data on population size in three populations of *B. acrocnema* located in the San Juan Mountains in southwest Colorado. Based on these data, I also evaluate the conservation status of the butterfly.

Materials and Methods

Study Organism. Like some other alpine butterflies, *Boloria acrocnema* is thought to have a biennial life cycle (but see Seidl 1996): each cohort overwinters twice and development occurs over three summers, thus creating odd- and even-year broods (Scott 1982, Brussard & Britten 1989). Eggs oviposited the first summer develop into first instar larvae that same summer and overwinter. The following summer, development through third instar occurs. The third summer, larvae develop through fifth instar, pupate and eclose as adults, which live for approximately seven to nine days (Scott 1982). Britten and Brussard (1992) found no significant genetic differences between the two broods at two colony sites. Population estimates have therefore been characterized as either odd- or even-year broods (Gall 1984a, Brussard & Britten 1989).

Boloria acrocnema specializes on snow willow, *Salix reticulata* L. ssp. *nivalis* (Hooker) Löve et al. (Salicaceae), a common plant restricted to mesic alpine areas in Colorado (Weber 1987). Females exhibit oviposition preference for snow willow (Seidl 1996) and larvae followed in the field feed exclusively on it (Seidl 1995). However, in captivity *B. acrocnema* larvae will feed on *Salix arctica* (Scott 1982), a close relative to *S. reticulata nivalis*, despite no evidence of the use of this plant having been documented in the field.

Study Sites. I conducted population demographic research from 1990–94 at three *B. acrocnema* colony sites: (1) a colony at Mt. Uncompahgre, the type locality (UP1); (2) a colony within four km of the type locality (UP6); and (3) a colony on Redcloud Peak, ca. 20 km southeast of the type locality (RC1). All colonies are found in glacial cirques with a northeast exposure and range in altitude from 3800–4093 m, with UP1 being the highest in elevation and UP6 the lowest. Each colony site is located in alpine tundra habitat and each contains abundant patches of the butterfly's willow host, *S. reticulata nivalis*. The area encompassed by each of the sites differs—RC1 is ca. 15 ha, UP1 is ca. 20 ha, and UP6 is less than 5 ha. All three study sites occur within public lands: UP6 and UP1 are located in the Big Blue Wilderness Area of the Uncompahgre National Forest, and RC1 is within Bureau of Land Management lands. Hiking trails to both peaks pass through *B. acrocnema* habitat.

Population Abundance. The Pollard transect technique, a simple-to-use, non-intrusive method which identifies trends in butterfly abundance (Pollard 1977,

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TABLE 1. Relative population estimates and indexes of abundance for populations of *Boloria acrocnema* 1978–1996, Hinsdale County, Colorado. Prior to 1988, capture-mark-recapture methods were used to estimate population size. Beginning in 1988, Pollard transect methods were used to derive an index of abundance from which a relative population estimate was determined.

	Colony[1]			
Year	RC1	UP1	UP6	Source
1978	NA	NA	NA	Gall 1984a
1979	NA	600[3]	NA	Gall and Sperling 1980
1980	NA	700	NA	Gall 1984a
1982	1000	500	NA	U.S. Forest Service Files
1987	250–300	4	3	Brussard and Britten 1989
1988	492	200	2	Brussard and Britten 1989
1990	768	NA	NA	this paper
1991	1624	0	20	this paper
1992	948	878	414	this paper
1993	2408	452	2266	this paper
1994	3464	2918	442	this paper
1995	11773	6682	1979	Ellingson et al. 1995
1996	3670	2163	130–200	Wasinger et al. 1997

[1] 1990–1993 estimates were originally derived without intercalculating missing days during the flight season (Seidl & Opler 1994). The data reported here have been reanalyzed such that missing days are calculated as the average of the previous day and the two following days (Cook et al. 1967, Watt et al. 1977).

[2] Gall and Sperling (1980) state that several hundred individuals were seen on 30 July, 1978 but a population estimate for the brood was not calculated.

[3] Gall (1984b) estimated 150–180 individuals at peak flight in 1979 at UP1. In 1980 peak flight estimates of 200 individuals were estimated and found to be associated with a final population estimate of ca. 700, i.e., 3.5 days at peak flight. With this in mind, I have tabulated an approximate population estimation for UP1 in 1979 to be ca. 600, i.e., 3.5 days * 165 individuals.

[4] During the 1990 flight season I visited UP1 twice and UP6 a single time. These visits do not constitute a thorough search and therefore are specified as NA.

Thomas 1983, Pollard & Yates 1993), was adopted in 1987 to assess trends in *B. acrocnema* abundance (Brussard & Britten 1989). This method is employed by the British Butterfly Monitoring Scheme (Pollard & Yates 1993) and enables researchers to assess population abundance with less intrusive sampling. The main criticism of the Pollard monitoring method is that absolute population estimates cannot be derived from the data since only trends in abundance are recorded and not the fate of individuals *per se*, as in capture-mark-recapture methods (CMR). However, over a long-term monitoring period, the Pollard method can be equally as effective in assessing the condition of butterfly populations (Pollard & Yates 1993).

The method includes laying fixed transect lines in a monitoring area that includes both suitable and less suitable butterfly areas (Pollard & Yates 1993). Since I was concerned that fixed transect lines would disturb *B. acrocnema* habitat, I set new transect lines each field season, placing 100 m long transects in areas of high butterfly density. Transects were walked in the morning and only under favorable conditions: low wind, relatively full sun, and no precipitation. If conditions turned unfavorable, counts were halted to allow poor weather to pass. Transects were walked at approximately 10 min per 100 m transect. Individuals were included in the count if they occurred within five meters on either side of the transect line.

Pollard transects were carried out at the RC1 colony site during the field seasons of 1990 through 1994 and at the UP1 and UP6 colony sites in 1991 through 1994. Searches for *B. acrocnema* were begun each year in mid to late June. Once butterflies were found, transects were laid and counts were begun within three to five days. Three transects were laid each year at UP6, three to four transects were laid at UP1 each year, and five to eight transects were laid at RC1 each year. The number of transects laid at each site and each year varied with the number of high density butterfly areas found. If a day was missed during the flight season, interim day counts were estimated. These values were derived as the average of the preceding day and two days following the missing transect count after Cook et al. (1967) and Watt et al. (1977).

To determine the relationship between Pollard transect indices of abundance and population estimates, and to derive a *relative* population estimate for comparison among years, CMR experiments were conducted simultaneously with Pollard transects in 1987 at RC1 (Brussard & Britten 1989). Pollard transect data were found to account for approximately 10% of the population estimates derived from CMR methods (Brussard & Britten 1989). Based on these calculations, each daily transect count (ti) was multiplied by 10 to derive the *relative* daily estimate (Ni) for a colony.

In addition, Gall (1984b) derived a residency rate for *B. acrocnema*. A residency rate (r) is defined as the fraction of animals on day i that remain in the population on day i+1 and calculates the probability that an individual counted on day i is recounted the following

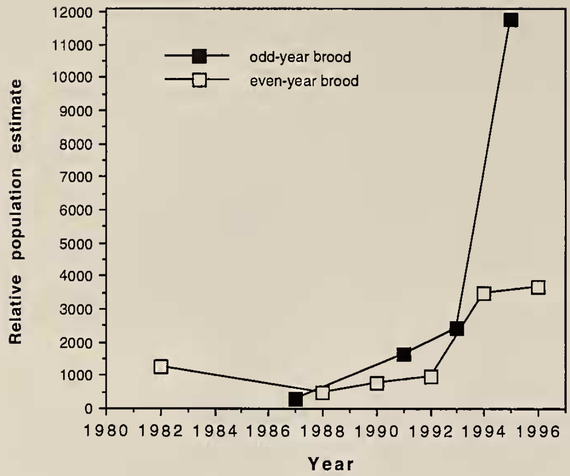

FIG. 1. Relative population estimates for *Boloria acrocnema* at Redcloud Peak, colony site RC1, based on Pollard transect method.

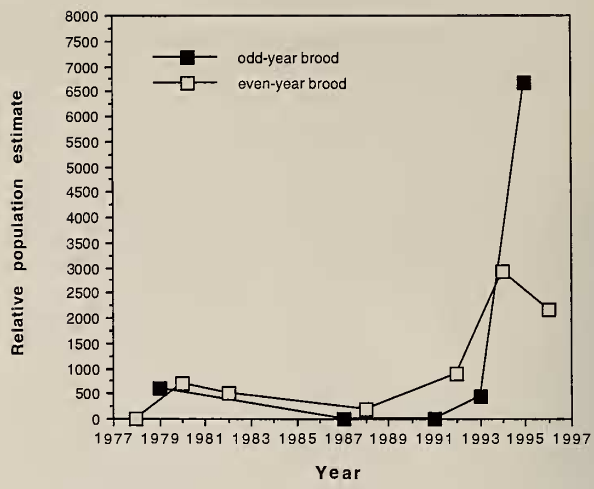

FIG. 2. Relative population estimates for *Boloria acrocnema* at Mt. Uncompahgre, colony site UP1, based on Pollard transect method.

day (Gall 1984b). Residency rates for *B. acrocnema* at UP1 in 1980 were calculated as 0.46–0.70 (Gall 1984b). Therefore, transect counts in this study, and those in Brussard and Britten (1989), were multiplied by the average daily loss rate (1-r) or 0.4.

Total population indices were summed across days to arrive at a relative population estimate for a colony for a given year.

RESULTS

The even-year population at RC1, initially estimated at maximally 1000 individuals (Gall 1984a), had declined to a count of 492 in 1988 (Brussard & Britten 1989). During this study however, the even-year population increased significantly and relative population estimates for the even-year population include: 768 in 1990, 948 in 1992, and 3464 in 1994 (Table 1, Fig. 1). Similarly, the odd-year population at RC1 increased from 1980's levels; in 1991 and 1993 estimates were 1624 and 2408 respectively (Table 1, Fig. 1).

At UP1, the type locality for *B. acrocnema*, no individuals were seen in 1991, despite a concerted search effort that lasted from July 1 through July 25. However, in 1993 an estimate of 452 was calculated (Table 1, Fig. 2). For the even-year brood, relative population estimates of 878 and 2918 were recorded in 1992 and 1994 respectively (Table 1, Fig. 2).

When the UP6 colony of *B. acrocnema* was discovered in 1988 only two individuals were recorded (Brussard & Britten 1989). An estimate of 20 individuals in 1991 supported the notion that this was a small colony (Table 1, Fig. 3). However, in 1992 and 1994 estimates of 414 and 442 respectively were recorded (Table 1, Fig. 3). And in 1993 the odd-year brood rose to an estimate of 2266 (Table 1, Fig. 3).

DISCUSSION

Population Biology. Even- and odd-year broods at all three colony sites surveyed in this study have either stabilized or increased when compared to 1980's estimates (Table 1). Original population estimates at RC1 and UP1 were surpassed in 1993 and 1994 and the colony at UP6 grew substantially (Table 1).

In addition to the population data reported here, more current estimates have also been calculated by Colorado Heritage Program researchers using similar methodology (Ellingson et al. 1996, Wasinger et al. 1997). In 1995, the odd-year estimate for RC1 was 11,773, an order of magnitude higher than any odd-year estimate calculated prior to 1995 at that site (Ellingson et al. 1996). Large population estimates were also found at Mt. Uncompahgre colony sites in 1995: 6682 at UP1 and 1979 at UP6 (Ellingson et al. 1996). Although the UP6 estimate is reasonably close to the previous odd-year brood, the estimate at UP1 is more than twelve times as large.

While 1995 estimates were dramatically different from 1993 estimates, 1996 estimates derived by Colorado Heritage Program researchers were more similar to those found in 1994. For instance, the estimate at RC1 in 1996 was 3670 (Wasinger et al. 1997): in 1994 I found 3464 (Table 1). At Mt. Uncompahgre, the estimate at UP1 was 2163 in 1996 (Wasinger et al. 1997) and 2918 in 1994 (Table 1). Finally, the estimate at UP6 was 130–200 individuals in 1996 (Wasinger et al. 1997) and 442 in 1994 (Table 1).

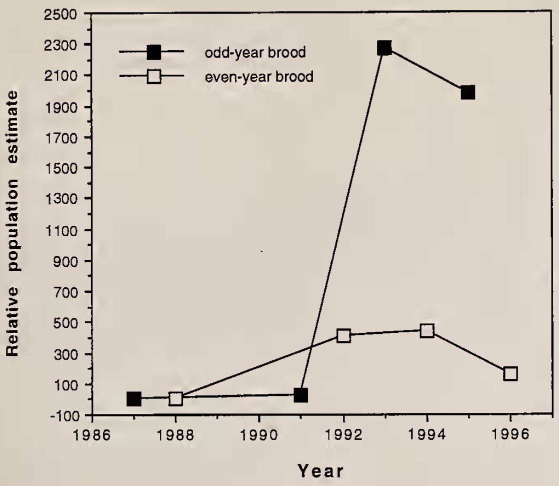

FIG. 3. Relative population estimates for *Boloria acrocnema* at Mt. Uncompahgre, colony site UP6, based on Pollard transect method.

Data from 1990–96 provide strong evidence that *B. acrocnema* is on a trajectory toward stabilization or increase. Yet the following caveats need to be mentioned: 1) employing the CMR calibration calculation of 10% to transect counts may lead to inflated estimates since the CMR results from one colony site may be not transferable to other sites; and 2) residency rates may change between years and are largely determined by the geographical area that the colony inhabits. For instance, the UP6 colony site is one third the size of UP1 and RC1: three transects at UP6 include the majority of available *S. reticulata nivalis* habitat. Therefore, the likelihood of counting individuals on day i+1 that were present on day i is higher at UP6 than at RC1, due to the differences in area and assuming all else being equal. To remedy these problems in deriving present relative population estimates, CMR experiments and local residency rates should be calculated for all colony sites. Those values should then be used to translate Pollard transect data into population estimates.

Conservation Status. Collecting pressure in the early 1980's was reported to be intense and some collectors extracted more than 50 specimens at any given time (P. A. Opler, pers. comm.). Although there are no studies that show collecting to be the cause of local extinction in Lepidoptera (Pyle et al. 1991), studies of vertebrate fauna demonstrate that overharvesting can reduce genetic variability and heterozygosity (Bonnell & Selander 1974, O'Brien et al. 1989, Barrowclough & Gutiérrez 1990). Conservation biologists assume that populations with greater genetic variability are better able to survive and evolve in changing environments (Avise 1994).

Livestock grazing is the second force proposed by some to have affected *B. acrocnema* (Seidl & Opler 1994). Sheep grazing in the alpine environments of the San Juan Mountains began in the mid 1800's (Lake City, Colorado Historical Society) and continues into the present. Foraging and trampling by sheep may result in lower seedling survival of both nectar sources and host plants (Owens & Norton 1992).

Both collecting and livestock grazing have been prohibited or suspended since *B. acrocnema* was federally listed in June 1991, presumably shielding the species from these pressures. However, local climate change and a consequent drying trend have not abated. Weather data collected over the last two decades indicate a trend of below-average snowfall and higher-mean ambient air temperatures for southwestern Colorado (Colorado Avalanche Center, Denver, Colorado).

It has been demonstrated that weather can influence butterfly populations (Pollard 1988, Pollard & Yates 1993) and that catastrophic weather events may bring about local butterfly extinction (Ehrlich et al. 1972, Singer & Thomas 1996). Based on the unusual distribution and microhabitat requirements of *B. acrocnema*, its relict arctic history, specialist nature, and mesic habitat requirements, this species may be an excellent indicator of the effects of climate change in alpine environments. Although some species may migrate to cooler northern latitudes (Parmesan 1996), species with low vagility like *B. acrocnema* may be limited in their dispersal capabilities (Dennis & Shreeve 1991, Murphy & Weiss 1992, Britten et al. 1994). Changes in host plant quality, phenology and distribution are also likely as plants respond to changing abiotic conditions (Dennis & Shreeve 1991). Butterfly abundance may be affected as host plants become less palatable or less available (Dennis & Shreeve 1991, Pollard & Yates 1993).

Britten et al. (1994) suggested that *B. acrocnema*'s low population numbers in the late 1980's were due to human-induced factors including climate change and that the butterfly was headed for extinction. The data I have reported here suggest that the butterfly has recovered from its low population numbers. However, I believe Britten et al. (1994) raised important questions concerning the effects of climate change on *B. acrocnema* and other high altitude mesophilic butterflies. To address their concerns, careful analysis of how climate change parameters (rising ambient temperatures, increased UVB, elevated CO_2 levels, etc.) affect the larvae and adults of *B. acrocnema* (or a close surrogate due to its endangered status) is needed. These experiments will provide essential evidence in identifying current and potential effects of climate change on *B. acrocnema* and will help to predict the species' future population dynamics and its probability of extinction under a climate change model.

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